Chapter 8
Guidelines for Planning Tidal Inlet Monitoring

8-1. Introduction

a. The purpose of this chapter is to provide guidance to the field engineer in planning prototype monitoring of physical processes at tidal inlets. Processes in and near tidal inlets may be monitored to evaluate the feasibility of proposed inlet modifications; to investigate the impacts of existing modifications, such as a deepened or stabilized channel; to ascertain inlet safety issues relating to navigation and pollution control; and/or to provide information for subsequent numerical or physical modeling of the inlet. Tidal inlets are dynamic coastal features that migrate, shoal, and change their shape in response to various physical processes. These processes can be studied through physical or numerical modeling, or prototype (field) measurements. This chapter provides guidelines for planning and conducting prototype measurements at field sites. These guidelines are intended to be generally applicable throughout the United States, but must be adapted for project requirements.

b. Many monitoring programs have been implemented by the USACE at inlets in the United States. Under the USACE Monitoring Completed Coastal Projects Program (MCCP), the following inlets have been monitored for various time periods since inception of the program in 1981: East Pass, Florida (Morang 1992); Yaquina Bay, Oregon (in planning stages); Siuslaw, Oregon; Colorado River, Texas (White 1994); Carolina Beach Inlet, North Carolina (Jarrett and Hemsley 1988); Ocean City Inlet, Maryland; and Manasquan Inlet, North Carolina. Other inlets monitored by the Corps include: Indian River Inlet, Delaware (Anders, Lillycrop, and Gebert 1990); Oregon Inlet, North Carolina (monitoring under way); Port Everglades, Florida (Rosati and Denes 1990); Panama City, Florida (Lillycrop, Rosati, and McGehee 1989); Murrells Inlet, South Carolina (Douglass 1987); and Little River Inlet, South Carolina (Chasten and Seabergh 1992). For a detailed discussion of the specific monitoring programs at each of these inlets, the reader is directed to the references cited. This chapter illustrates various levels of a monitoring program through discussions of a few of these monitoring projects.

c. Instructions for using and analyzing data from individual instruments is beyond the scope of this chapter. This chapter is directed towards broad guidance on planning a monitoring project, listing the types of equipment available, and describing data that can be collected at an inlet. Some types of measurements may require contracting to outside organizations, as the facilities, equipment, and expertise may not be available in-house.

8-2. Overview

a. Ideally, an inlet monitoring project is divided into three phases: (1) reconnaissance; (2) preliminary measurements; and (3) detailed field study. Each phase level includes the process critical to a successful monitoring program: proper planning. During the planning process, data needs, measurement devices, and data analysis tools are identified to ensure that the type, duration, and frequency of required information will be obtained. Analysis of observations and data should be conducted during and/or after each phase.

b. Various types of data collection methods and instrumentation can be used to obtain field data at inlets, as indicated in Table 8-1. The methods listed are popular, proven methods for field use; other measurement techniques and instrumentation are available for other applications. Each measurement method/device has inherent limitations, e.g., required deployment location, length of deployment, frequency of data sampling, how the data are stored and retrieved, environmental conditions under which the technique/instrument will properly perform, theoretical assumptions in analysis of raw data, etc. Choosing the method/device to measure a particular type of data will depend on its limitations, availability, and cost, perhaps requiring outside expertise.

c. Monitoring programs are usually initiated to (1) evaluate pre-construction site processes so that a project can be properly designed with analytical, physical, or numerical models; (2) evaluate post-construction success of an inlet modification; or (3) assess existing conditions and trouble-shoot processes that may be causing a particular problem. Every field study requires an initial reconnaissance, primarily to assess what is known about the site. The reconnaissance phase may simply be a site visit supplemented with information gathered through a literature search, or may extend to preliminary field observations with low-cost measurement techniques. The reconnaissance can suggest a hypothesis to test and a scheme for field data collection. Based on the reconnaissance objective, the project engineer can then decide if a preliminary, relatively inexpensive study is to be conducted or if a more thorough, detailed study is in order. Sometimes, the preliminary field study identifies additional conditions that need to be monitored in detail, ultimately resulting in a study that has included all three phases.

Table 8-1
Data Needs and Associated Instrumentation for Inlet Monitoring Projects

Data Desired	Data Collection Method/ Instrumentation Types
Circulation patterns	Surface and/or subsurface drogues, dye
Current speed and direction	Acoustic Doppler Current Profiler (ADCP) Electromagnetic Current Meter (EMCM) Ducted impeller (self-aligning)
Wave height, period, and direction	Pressure sensor (nondirectional) Pressure sensor with EMCM Pressure sensor array Accelerometer-based buoy (deep water)
Wind speed and direction	Vane-mounted anemometer Propeller-driven anemometer Cup-type anemometer
Water/tide level	Absolute water pressure sensor and barometer Tide gauge (stilling well and acoustic level detector)
Suspended sediment concentration/rate	Sediment traps Optical Backscatter Sensors (OBS) Fluid/sediment sample jars
Total sediment transport rate	Sediment traps Sediment tracer
Bathymetry	Rod and level Boat with fathometer Sled SHOALS (Scanning Hydro-graphic Operational Airborne Laser System) SEABAT (multi-beam acoustic sounding system)
Topography	Rod and level GPS-tracked (Global Positioning System) vehicle Stereoscopic aerial photography
Information about bed forms or structure conditions	Diver inspection Aerial photography (with clear water) Side-scan sonar SEABAT (see above)
Surface/subsurface exploration	Sediment grab samples Sediment cores Subbottom profiler

d. Occasionally, unexpected field conditions (due to weather patterns, wave climate, navigational traffic, dredging activities, etc.) may create a “target of opportunity” to gain some insightful information about inlet processes. Keeping in mind the intent of the monitoring program and required data, the field work plan should accommodate flexibility so that unique field conditions can be captured.

e. The purpose of a monitoring program may be to provide information for numerical model calibration and verification, and/or to provide input data for physical models. In these cases, specific types of data and sampling site locations may be called for in the numerical/physical model, and should be addressed in the monitoring program.

8-3. Phase I: Reconnaissance

The reconnaissance phase of the study is a vital prelude to the later field measurements. Much of it can be conducted at the home office, although at least one field visit by the project engineer is required.

a. Planning. Prior to visiting the project site, the project engineer should be familiar with the site as it is discussed in the literature, including previous studies concerned with the site (laboratory, numerical, and field) which may give insight into inlet processes. Measurement techniques which have been successful at locations with similar processes and/or navigation traffic should be considered for the project site monitoring. A preliminary monitoring plan should be developed, including data requirements, types of instrumentation, time scale for the measurements, and proposed sampling locations. The National Oceanic and Atmospheric Administration (NOAA) tidal current and height tables published by NOS present predicted current and tidal height information for inlets along the Atlantic, gulf, and Pacific coasts. These tables are published approximately 6 months prior to the referenced year; therefore, the project engineer can plan a reconnaissance visit to coincide with predicted conditions of interest (i.e., peak currents, spring tide, etc.).

b. Literature search. An extensive literature base exists concerning tidal inlets, and technical information may be available for a study area. If documentation of processes or previous studies at the project site is scarce, reports discussing inlets with similar histories and processes may be useful. Sources for such information include:

(1) Reports prepared by U.S. Government agencies, such as the USGS and the USACE. The GITI program conducted by USACE produced many site-specific and comprehensive reports about inlets. USACE District and Division offices may have reconnaissance and feasibility studies for the inlet of interest.

(2) Congressional documents.

(3) Reports by academia, such as those in the libraries of Louisiana State University's Coastal Studies Institute, and the University of Florida's Coastal and Ocean Engineering Laboratory.

(4) Conference proceedings often have several case studies describing inlet research, including discussions of processes at inlets, monitoring programs, and applications to numerical and/or physical modeling.

(5) Scientific journals such as the *Journal of Sedimentary Petrology, Journal of Geology, Marine Geology, Journal of Waterways, Ports, Coastal, and Ocean Engineering*, and *Journal of Coastal Research*. Scientific publishers such as Elsevier or the Society of Sedimentary Geologists (SEPM) have printed excellent books containing papers which describe the results of coastal research and engineering (examples include Elsevier's Lecture Notes on Coastal Engineering, SEPM Special Publications, and some of the Geological Society of America Memoirs).

c. Data search. Data (current, wave, and water level measurements, core logs, bathymetric, topographic, subbottom/seismic data, surface sediment samples, tidal/river stage data, aerial photographs, and/or dredging records) may be available from previous field studies. Sources for such data include:

(1) District offices of USACE. Historic maps, hydrographic surveys, and topographic sheets may be available.

(2) Other Federal agencies. The NOAA archives tide data, and limited hydrographic surveys dating back to the 1800s. The National Climatic Data Center has weather data from around the country. Offshore wave data may be available from the U.S. Navy for certain areas. The USGS produces topographic sheets for the United States.

(3) State agencies. Departments of natural resources and environmental regulation often have sediment samples, beach profiles, coring records, and geophysical data.

(4) Universities. Schools with oceanography, geology, or coastal engineering departments may have inlet process data.

(5) City Governments. Cities with active engineering departments.

d. Field visit.

(1) A site visit allows the project engineer to observe inlet processes, process interaction with structures, and inlet effects on adjacent beaches. The preliminary monitoring plan developed in planning stage (*a*) can be evaluated for its feasibility, and revised if necessary. Observations of dye movement through the inlet/structures, measurements of currents with hand-held current meters, and Littoral Environment Observations (LEO) (Schneider 1981) of wave conditions are simple, inexpensive methods for quantifying site processes. Discussions with local citizens, harbor masters, and city/county engineers can provide useful information about inlet conditions during normal and storm conditions, navigation/recreational hazards to instrument deployment, and public perception of inlet effects.

(2) It is usually cost-effective for the project engineer to charter an airplane to fly over the site. This overview helps fix the inlet within the broader geologic and geographic framework. Features which may be obscure from the water surface or the ground may be clear from the air, e.g., sediment plumes within the inlet or sea, bed forms, ebb/flood tidal shoals, beach ridges, and ponds which may mark former inlets. An airplane with the wing over the cabin and windows that open is recommended for the best quality photographs/video. An altitude between 300 and 600 m (1,000 and 2,000 ft) is ideal, although in some areas aircraft are not permitted to fly this low. A helicopter, which can hover over a site, can be an attractive alternative to a plane. However, vibration from the helicopter may degrade photographs/video, and the rental cost for helicopters is an order of magnitude greater than that for airplanes.

e. Controlled aerial photographs. Sources for aerial photography include:

(1) USACE.

(2) U.S. Air Force.

(3) National Atmospheric and Space Administration (NASA).

(4) U.S. Department of Agriculture.

(5) State agencies, as discussed in *c*3 above.

(6) City engineering departments, as listed in *c*5 above.

(7) Private aerial photography companies in vicinity of the inlet.

It is worth obtaining as many historical photographs and/ or hydrographic surveys as possible because they often reveal the natural behavior of an inlet and demonstrate how it migrated over time. Older photographs taken before structures affected natural processes in the vicinity of the inlet give great insight into structure impacts and natural inlet processes.

f. Example of a reconnaissance level study: Port Everglades, Florida.

(1) The purpose of the Port Everglades, Florida, monitoring program was to evaluate the effectiveness of a structure sealing project at the south jetty, a rubble stone structure with large "man-sized" voids (Figure 8-1). Beach fills placed south of the inlet eroded at an extremely high rate, indicating to county and state personnel that sediment moved through the south jetty into the navigation channel. The structure was sealed with sodium silicate-cement for void cavities and with sodium silicate-diacetin for sand-filled voids during the period September-November 1988. Four site visits were conducted as part of the monitoring program: (a) reconnaissance study, (b) preconstruction experiment, (c) during-construction inspection and observation, and (d) post-construction experiment. The Port Everglades study is described by Rosati and Denes (1990).

(2) The purpose of the reconnaissance study, conducted 27-29 June 1988, was to obtain detailed information about the south jetty infrastructure, current patterns, and surrounding beach and bathymetry conditions to plan later phases of the monitoring program. Using the NOAA tidal current tables, the trip was scheduled such that extreme conditions (peak flood and ebb currents) occurred during daylight hours, and could easily be evaluated. A literature review revealed that the county had conducted a dye study at the site in February 1985 by placing dye on one side of the jetty and making visual observations of dye movement through the structure as an indication of structure permeability. Permission to access the site and operate from a staging area was obtained prior to the reconnaissance study period. Proposed plans for assessing pre- and post-construction structure permeability included: dye movement through/around structure; current speed and direction through/around structure; and sediment transport through structure (using sediment traps and/or a bed-load sampler). The feasibility of making each type of measurement during the pre- and post-construction experiments was evaluated during the reconnaissance study.

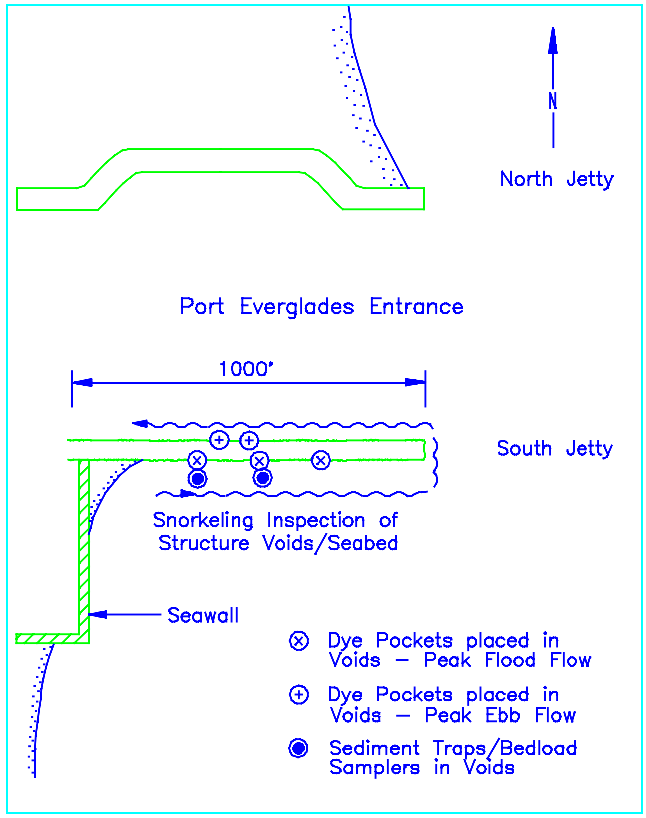

Figure 8-1. Data collected during the Port Everglades, Florida, reconnaissance field study

(3) A snorkeling inspection of structure voids, recording their location and dimensions, was initially conducted. Several structure voids that extended deep into the structure were identified and photographed for possible placement of current meters and sediment traps during future experiments. Characteristics of the seabed were also noted during the snorkeling inspection. No shoals or large sediment deposits were noted along the structure, indicating that if sediment passed through the structure, it was carried away from the sides of the jetty.

(4) A hand-held current meter was brought to the site to evaluate currents at locations along the structure; however, the equipment failed and a replacement current meter could not be obtained in a timely manner.

(5) Dye placement using a pressure sprayer did not provide the continuous, concentrated quantity of dye required. Instead, powdered dye placed in sediment sample bags weighted with rocks and placed in structure voids provided an observable dye pattern. Observations of dye dispersal were made over the experiment period

for three peak flow conditions, both from the ground and from a rented airplane.

(6) A sediment trap and bed-load sampler were placed in structure voids over several hours, and removed to measure the accumulated sediment. Both types of sediment measurements collected very little sediment. It was decided that the sediment traps and bed-load samplers would not be used to measure sediment transport through the structure in later phases of the monitoring program.

(7) It was concluded that dye dispersal through the structure provided the best measure of structure permeability. A fluorometer, an instrument that quantifies fluid florescence, was used in later phases of the monitoring program to determine the rate of dye dispersal through the structure. Using dimensions of the structure voids, three current meter mounts were designed, and the mounts were used to position 2.5-cm (1-in.) electromagnetic current meters in voids for pre- and post-construction experiments. These two types of measurements were used to quantify pre- and post-construction structure permeability at the Port Everglades south jetty.

8-4. Phase II: Preliminary Measurements

a. General. This phase of an inlet study is intended to either answer a specific question with a limited amount of field data or provide general information which can identify problem areas and be used to plan a more detailed field survey. For projects with limited scope or funding, this effort may be the only field study performed. In some cases, the collection can be designed to compliment similar data being obtained in the vicinity of the inlet by other agencies. An example is the measurement of water levels. NOAA might have a tide gauge within an inlet or harbor. In this case, a single additional tide gauge could be deployed along the open coastline so that the tidal phase difference between the bay and sea can be measured. Another example is the use of side-scan sonar to examine an inlet structure. Once the vessel and side-scan equipment have been mobilized, the equipment can be used to image bed forms within the inlet for a relatively small additional cost. Examples of the types of data that might be collected in a preliminary site survey include:

b. Controlled aerial photographs.

(1) Aerial photographs taken under controlled conditions can be used for mapping, identifying landforms, and sometimes identifying relic channels. If inlet features change shape significantly during the year, a winter flight and a summer flight are recommended. If other aerial photographs already exist for the study area, it is recommended that the new photographs be taken at the same altitude and with the same lens focal length to produce images that are the same scale as the original photos. Otherwise, two scale factors are recommended, 1:24000 to provide broad coverage of the study area, and 1:4800 to produce detailed images. If the water is clear, the 1:4800 photographs will have enough resolution to show inlet bed form features.

(2) Daylight quality should be considered when planning aerial photography. If seafloor features are of primary interest, then the photographs should be taken at midday when the sun is high and has greatest penetration through the water. If land features are of primary interest, then low-angle sunlight is preferred because long shadows help reveal features.

(3) Tidal stage is also an important consideration. At most inlets, the flood tide carries clear water into the inlet, which may facilitate photographing bed forms. Photographs during ebb flow water may be undesirable due to turbid river inflow or sediment suspension from a back bay area. Another (possibly conflicting) consideration is adjacent beach shoreline position as it varies with tidal stage. It is convenient to take aerial photographs at a known phase of the tide, i.e., mean low water (mlw), mean high water (mhw), etc., which facilitates comparison with beach surveys and/or previous aerial photographs.

c. Beach profile/inlet shoreline surveys. Beach profiles can be obtained with simple equipment (rod and level) at low cost. Many sites have previously surveyed reference locations; resurveying these locations allows direct comparison with earlier surveys. Sometimes the most difficult part of beach surveys is obtaining permission from local residents to use their property as a right of way to gain access to the beach.

d. Sediment sampling. Surface sediment samples can be collected by the field workers who perform the profile surveys. Ideally, samples should be taken within the inlet, from adjacent beaches, and from the bay behind the barrier beaches. These sampling locations can help identify the source of the sediment and suggest whether there is a net amount of sediment entering the bay or flushing out to sea. The samples should be taken from various parts of the beach profile since grain size can vary significantly across the beach. In addition, it is important that sample locations be recorded since it may be necessary to resample the same locations in the future.

e. Currents. The speed of water flowing through an inlet is basic information which is often unavailable. Measurements can be made using either in situ current meters (discussed in the next section) or surface or subsurface drifters. Drifters can be prepared inexpensively and provide basic information about current speed. The easiest method is to position painted blocks of wood or oranges/grapefruit in the inlet and time how long they take to travel a known distance.

f. Water flow patterns.

(1) Drifting floats and dye can be used to show how water flows through the complex inlet system. Drifters can provide only limited quantitative information about the volume of water in the system, but can demonstrate overall patterns such as whether certain channels are primarily ebb or flood dominated, if gyres occur around structures, and how different bodies of water interact. A drifter or dye study can be performed as part of the reconnaissance phase of monitoring or can be done in conjunction with more detailed current meter measurements in the Detailed Field Study phase. Dye is useful in indicating the relative permeability of structures during various phases of tidal flow. An experiment with drifters or dye can be performed relatively easily since material costs are modest and observations can be made from ground or a rented airplane. The main disadvantage of these inexpensive devices is that they must be used in relatively good weather so that they can be accurately tracked. Drifters with radar reflectors are available and are an alternative to consider if the weather is often poor at the study site, but the complexity of the radar and navigation equipment adds significantly to the cost.

(2) Drifters used on the water surface can simply be plywood shapes painted with fluorescent paint and numbered for identification. To trace the flow of water below the surface, a drifter can be made with vanes suspended below the surface float at the desired depth. These drifters can be difficult to use because the vanes can get caught on underwater obstructions or a shallow bottom. The surface float also produces some drag, so the resultant velocity vector may not accurately describe either the surface or subsurface speed and direction.

(3) Dye can be injected from a fixed point over a period of time, producing streak lines that can reveal areas of turbulence or mixing. Wright, Sonu, and Kielhorn (1972) used dye at East Pass, Florida, to demonstrate how sea water entering the inlet with the flood tide was subducted underneath a plume of fresh water flowing south out of the Bay. Rosati and Denes (1990) used dye at Port Everglades, Florida, to evaluate the permeability of the inlet jetty before and after structure sealing.

(4) Dye is available as a powder in bulk form, in pre-formed blocks or rings, and as a concentrated liquid. Dye rings are the most convenient to use, but tend to dissolve slowly. Powder and liquid are quickly dispersed, but can be messy to use. Two commonly used dyes are rhodamine, which is pink/red, and uranine, which is fluorescent green. Food colorings are available that have been tested for purity, and may be preferred for environmental considerations. Material Data Safety Sheets are available from the manufacturer for these food colorings, certifying that they are nontoxic. In areas where local residents are especially sensitive about environmental pollution, food colorings are recommended.

(5) In turbid conditions, dye is only visible at the surface. Formulabs, Inc. recommends that yellow/green dye be used in water bearing heavy sediment loads because red will be partially obscured by suspended clay particles. For turbid seawater conditions, it is advisable to use concentrated dye that has been mixed with fresh water, since this solution will float. If the water is clear, it may be best to mix powder with sea water at the site since this mixture will tend to remain at the depth of its injection. In inlets with rapid flow, dye may disperse too quickly to be visible. Before finalizing a monitoring program at the inlet, the feasibility of using dye and drifters at the site should be evaluated with testing.

g. Tide measurements. If there is a harbor near the project site, a tide gauge may already be located there. To determine the phase difference between tidal stage in the harbor and along the open coastline, another tide gauge will have to be installed, preferably near the inlet's mouth. Thus, short-term deployment of an inlet mouth gauge and comparison of these measurements with a harbor gauge will facilitate proper conversion of the long-term harbor tidal record.

h. Side-scan sonar.

(1) Side-scan sonar uses phased transducer arrays mounted on a towfish to emit acoustic pulses in narrow beams to each side. Timing of the return echoes permits computation of the slant range, perpendicular to the direction of towfish travel, to targets in the plane of the beam. Repeatedly pulsing the signal as the towfish is pulled forward generates a picture of the seafloor as a series of scan lines on a moving chart recorder. Stronger returns show darker images, and a lack of a signal appears white. The result is an acoustic image of the bottom as seen

from the position of the towfish (Clausner and Pope 1988). Side-scan sonar is a versatile tool that can be used to assess the condition of breakwaters or other structures and can image bed forms and other bottom features in inlets and channels (Lillycrop, Rosati, and McGehee 1989).

(2) The advantage of side-scan sonar is that it can be operated in turbid water, where aerial photography or diver inspection are ineffective. However, shallow water may limit its use. It usually is not effective in water depths less than about 3 m (10 ft), but if a shallow-draft vessel is used in calm seas, the side-scan towfish can be suspended just below the water surface. To reduce turbulence and optimize quality of the records, the side-scan surveys should be made at slack tide. Bubbles in the water column during ebb or flood tides may completely obscure the record. Turbulence caused by wave-current interaction and wave breaking near the mouth of an inlet may make this area difficult to image except on calm days.

(3) Because of the many difficulties in using side-scan sonar within an inlet, the likelihood of its success at the project site must be evaluated by comparing conditions under which it has been successful to the project inlet processes. The main cost of most side-scan projects is mobilizing the equipment, transportation of equipment and personnel to the project site, and leasing a vessel.

i. Example of a preliminary field study: Panama City, Florida.

(1) The Panama City, Florida, study was initiated in an effort to reduce dredging requirements in the inlet. Sand waves with heights as great as 15 ft in the entrance channel reduced the authorized channel depths, requiring frequent overdepth dredging. The purpose of the study was to evaluate potential changes to the inlet system that would reduce dredging requirements. Flow characteristics in the Panama City channel were such that sand waves formed; if these flow characteristics could be modified, the tendency for sand wave formation could be reduced. A limited amount of field data was obtained to (a) qualitatively monitor sand wave formation through time, (b) determine hydraulic characteristics of the inlet for numerical model calibration and verification, and (c) measure the velocity distribution associated with a fully developed bed form. A detailed discussion of the Panama City, Florida, project is given by Lillycrop, Rosati, and McGehee (1989).

(2) Bathymetric surveys were used to identify and locate individual bed forms within the inlet (Figure 8-2). Five parallel survey lines spaced approximately 30 m (100 ft) apart were used to monitor the sand waves, with surveys made in October and November 1986, and July 1987. Side-scan sonar was used to obtain a continuous picture of the bed features in November 1986.

(3) In April 1987, currents were measured with a hand-held ducted impeller meter (see short-term current measurements, next section) to determine the maximum tidal induced flow and the variation of near-bottom velocities near sand wave crests and troughs. In situ meters (see remote current meters, next section) with internal recording capability were deployed over several tidal cycles in July 1987. For ease of installation and protection from significant fishing boat traffic, gauges were mounted from taut moor buoys anchored to existing navigational buoy sinkers. Currents were recorded at 15- or 30-min intervals, depending on the gauge. Gulf and bay water level differences were measured by manual recording of tide levels on staffs placed at three locations during the same time period.

(4) Prototype data from Panama City were used to define existing conditions that create sand waves, and to obtain data to use in model calibration and verification.

8-5. Phase III: Detailed Field Study

The detailed field study is often complex and costly, and therefore must be carefully planned and coordinated, incorporating information gained from the earlier phases of the study. Examples of the types of data that may be collected during a detailed field study include:

a. Short-term current measurements.

(1) Short-term measurements of the current can be made intensively at several inlet cross sections over a tidal cycle. The measurements are typically made by field workers operating from small boats, although sometimes instruments can be deployed from a bridge if the span is not too high. Currents are usually hourly at three or four stations at each cross section, at depths of 0.8, 0.5, and 0.2 times the total water depth at each station. The resulting three-dimensional grid of current measurements gives an indication of current speed and direction, providing a detailed snapshot of water flow within the inlet. This information can help identify processes that may be contributing to problems in the inlet.

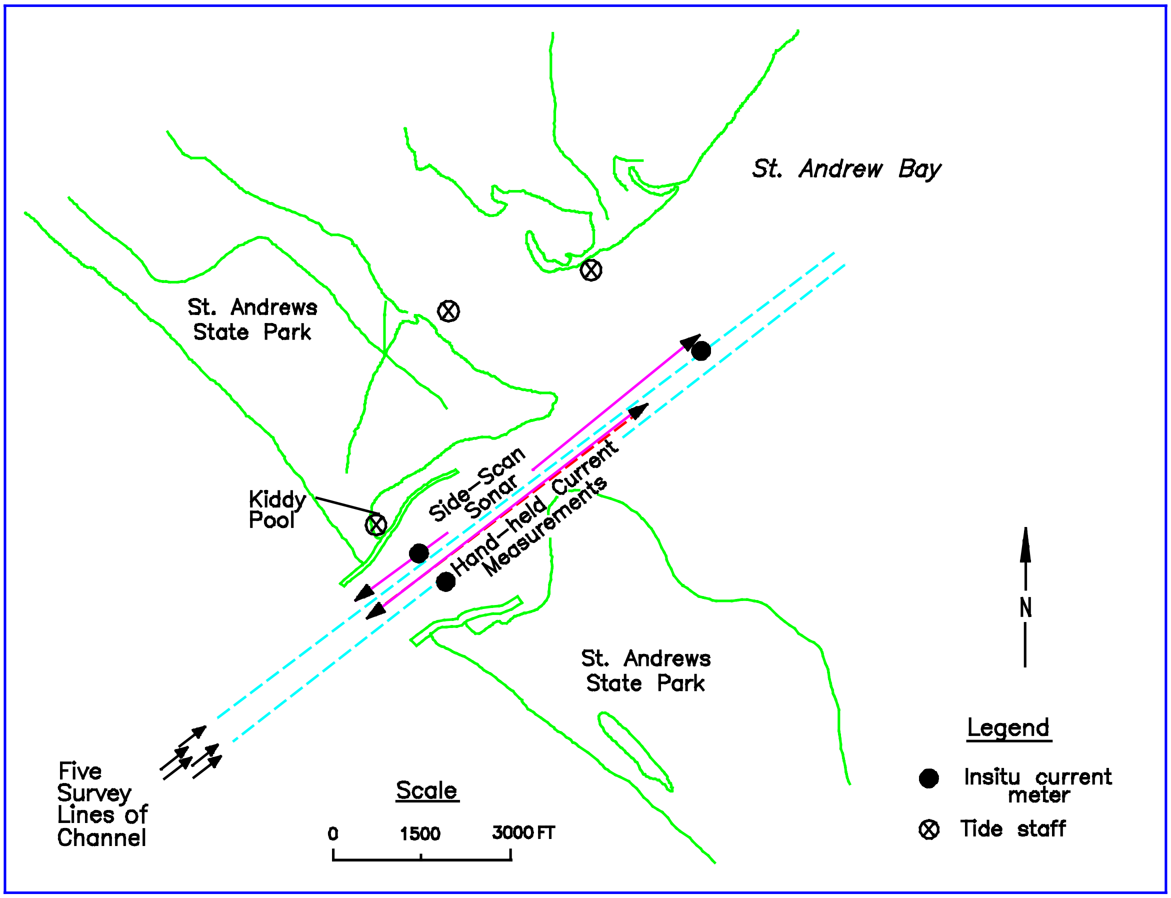

Figure 8-2. Data collected during the Panama City, Florida, preliminary field study (adapted from Lillycrop, Rosati, and McGehee (1989))

(2) However, a short-term measurement program is labor-intensive, and usually expensive. Often only one cross section at the inlet throat is monitored, where the most intense currents occur. Data collection is typically designed to coincide with spring or neap tide on the assumption that the currents will be the strongest. Other factors may also influence current speed and direction, such as runoff from rivers or complex interactions with other bay openings. It is recommended that the measuring period extend for at least 48 hr, and that some in situ current meters (discussed below) be deployed for an extended period. If the budget allows, measurements should be made several times during the year to learn more about seasonal effects on current speed and direction. If only one measurement period is possible, the study should be scheduled to coincide with the conditions under which problems at the site have been reported, or are likely to occur. For example, if structures have been damaged in spring, possibly as a result of increased river flow, then the study should be performed at that time.

(3) Significant changes in current patterns can occur while measurements are being taken, simply because all measurements cannot be made simultaneously without a large number of current meters and field workers. Significant current changes are most likely to be missed when the tides are turning. A way to reduce the likelihood of missing significant events is to perform the measurements at half-hour intervals during the tide change and at hourly intervals thereafter. Measurements during severe weather may indicate the most dynamic inlet processes, but field workers may not be able to stay safely at their stations.

b. Remote current meters.

(1) Many of the disadvantages of a short-term current measurement program can be alleviated by using remote current meters. Remote current meters can record data internally, or allow real-time reporting by sending data to shore via telemetry or cable. Data from internally recording (self-contained) meters are analyzed when the

meter is retrieved or the data are downloaded. Remote current meters are deployed by divers on a mooring during calm weather, left on station for a period of time, and recovered. If possible, they should be deployed for at least one complete lunar tidal cycle. Most internally recording meters can record flow speed and direction at 10- to 15-min intervals for a multi-week deployment; cabled or telemetered meters can stay on station indefinitely. This information can reveal subtle changes in the flow field as the tide turns, and can also show variations in maximum velocities over time. The greatest advantage of remote current meters is that they can record over conditions too severe for field workers, such as during the passage of storms or floods.

(2) Remote current meters are expensive, thereby limiting the number that can be deployed in an inlet. They must be located where they will not interfere with boat traffic, which can restrict their spatial coverage. If the meters are inadvertently in the path of trawlers or boat anchors, they can be damaged or lost. Frequent inspection of the moorings by divers can reduce the likelihood of loss, but adds expense to the project. Because most remote current meters record internally, the quality of data is unknown until the gauge is retrieved. If the gauge has malfunctioned, the data from that particular location may be lost. To help prevent equipment failure, the gauges should be thoroughly checked and calibrated prior to deployment.

(3) An ideal practice for a thorough field study would be a combination of both an intensive, manual current measurement effort accompanied with the deployment of remote current meters. The intensive field effort would provide spatial coverage, while the in situ meters would provide long-term temporal coverage.

c. Hydrographic (bathymetric) surveys.

(1) Large-area hydrographic surveys of a tidal inlet and the adjoining area can provide valuable information. Ideally, the surveys should include the inlet, the ebb tidal shoal and surrounding region, the flood tidal shoal, and back-bay channels that feed the inlet. The inlet and the offshore can usually be surveyed from a small boat, but a shallow flood tidal shoal may require rod and transit surveys. The surveys must be referenced to a standard datum.

(2) Although precision hydrographic surveys are labor-intensive and expensive, one should be conducted at the beginning of the field study, and another at the end if the study is of such a duration that significant bathymetric changes have occurred. These data can show changes in the inlet shape and orientation, and whether it is scouring or shoaling. If major construction, rehabilitation, or dredging is to be performed, the region should be surveyed before and after the work. Survey lines across the inlet can show the effect of the dredging on the navigation channels and on subsequent infilling or erosion. If current speed is obtained at various inlet cross sections, accurate survey information will allow the inlet's volumetric flow to be calculated.

d. Water level. Water level information should be obtained, either from an existing gauge, or a gauge specifically deployed for the monitoring period. The tide gauge should be deployed so that the measured water level can be referenced with respect to a standard datum. Water level information can be used in conjunction with the volumetric flow data to determine inlet tidal prism.

e. Wave information. Data on wave height, direction, and period are necessary for many inlet studies because wave-induced longshore currents can carry sediment to and from adjacent shorelines, damage structures, and be a significant process in forming ebb tidal shoals. Understanding these processes can help verify hypotheses about long-term trends at the study site. Offshore wave statistics are available for the Atlantic, gulf, Pacific, and Great Lakes coastal areas from the USACE Wave Information Study (WIS), which is based on hindcasting waves from meteorological data (Jensen 1983). Wave data are available from the National Data Buoy Center (NDBC) for 3- and 12-m (10- and 40-ft) discus buoys, which are in operation in the Great Lakes, Pacific, and Atlantic (Steele, Lau, and Hsu 1985; Steele et al. 1990). WIS statistics or NDBC data can be used to determine general trends for the project area, but complexities in local bathymetry and shoreline orientation at the study area can produce a local wave climate that is different from that projected using offshore data. Estimates of the nearshore wave climate can be obtained by using a numerical wave transformation model with local bathymetry and offshore wave data. To measure local waves, a directional wave gauge should be deployed within a few miles of the study area. If possible, the gauge should be in operation for at least 1 year so that a complete winter and summer cycle can be sampled. An 18-month deployment which covers two winters is preferable since the most severe wave climate occurs in winter for most of the United States. Exceptions would be those sites where there is significant ice cover during the winter. For these sites, the gauges should be recovered before winter so that they will not be lost during the spring thaw when drifting ice can gouge the seafloor.

f. Subsurface exploration. Inlet location and scouring/shoaling patterns may be controlled to some extent by underlying geologic structure. Clues that there might be structural control at a site are a stable inlet that has not migrated and rock outcrops on land, within the inlet, or offshore. Information about outcrop or regional structure may be available from the geological literature, but detailed exploration may be needed at some sites to plan construction or provide more information about long-term stability. Details on subsurface geology can be obtained from high-resolution geophysical surveys or from sediment cores. A combination of both is ideal: the cores provide control for the geophysics, and the geophysics provide a more regional image of the subsurface.

g. Detailed surface sampling. A comprehensive sampling program can be performed to learn more about source areas and transport patterns. In addition, sediment samples can be collected periodically if it is suspected that changes in sediment type occur during the year.

h. Sand tracer studies. Sand can be dyed and injected into the inlet system to trace sediment dispersion patterns. These studies would complement the drifter experiments described previously. Usually sand from the site is obtained, dyed, and washed with dish soap (to reduce clumping) prior to placement. The main disadvantages with the tracer experiments are that the sand may be dispersed too much to be traced, and counting sand grains is tedious.

i. Repetitive aerial photographs. At a site where the morphology changes throughout the year, periodic aerial photographs can be a valuable tool for mapping shoreline changes. At least two flights per year are recommended, with a "storm" flight reserved for severe northeasters or hurricanes that impact the site.

j. Meteorological data. Data on wind speed and direction should be collected during the hydraulic field studies. Weather records from nearby airports or military bases may be available. If not, a portable weather station can be established on a tower or pole near the project site. These data can reveal if wind setup contributed to unusual water levels in inlet back-bay areas.

k. Example of a detailed field study: Siuslaw River, Oregon.

(1) Under the MCCP, the Siuslaw River, Oregon, was monitored from 1987 to 1990 to determine the effectiveness of jetty "spurs." In 1985, the existing rubble-mound jetties were extended approximately 610 m (2,000 ft) seaward and 122-m-long (400-ft-long) spurs oriented at a 45-deg angle to the jetty trunk were constructed (Figure 8-3). Physical model studies conducted prior to spur additions indicated that the spurs would deflect material away from the structure, significantly reducing shoaling in the navigation channel. The objectives of the monitoring project were to (a) determine the effectiveness of the spurs in deflecting sediment, (b) identify shoaling patterns near the jetties, (c) compare existing prototype conditions to those predicted in the physical model study, (d) evaluate the effectiveness of the system in reducing maintenance dredging requirements, and (e) evaluate impacts of the jetties on the surrounding beaches.

(2) Bathymetric data extending alongshore for 10 km (6 miles) south of Siuslaw River and 8 km (5 miles) north, and offshore to an approximate depth of 7.6 m (25 ft), including some profiles perpendicular to the jetty in the vicinity of the spurs, were collected twice a year for 4 years prior and 5 years after spur construction (1981-1990).

(3) Dye dispersal, documented with video and aerial photographs, was conducted twice a year to indicate current patterns in the inlet and near the spur jetties. Seabed drifters were used in conjunction with the dye studies to indicate bottom current patterns. Bottom currents were also measured in the summer of 1990 by suspending a current meter with a 91-kg (200-lb) subsurface buoy from a helicopter. Current speed and direction at 22 locations in the vicinity of the inlet created a snapshot mosaic of current patterns for three different wave and current conditions during the field test. However, due to 21-m/sec (40-knot) winds, current patterns were primarily wind-dominated, and inlet-related currents were subdued. Under the MCCP, the current portion of the Siuslaw monitoring program was extended, and a similar helicopter current study was conducted during 1992 which successfully documented inlet circulation in the vicinity of the Siuslaw jetties (Pollock, in preparation).

(4) Side-scan sonar investigations of inlet and jetty conditions were conducted during a fall 1987 field test; however, wave conditions were too rough for boat maneuvering and the measurements were inconclusive.

(5) A directional wave gauge was deployed from September 1988 to September 1989 southwest of the entrance in 12-m-deep (40-ft-deep) water. Wave data during that year of deployment are being correlated with a

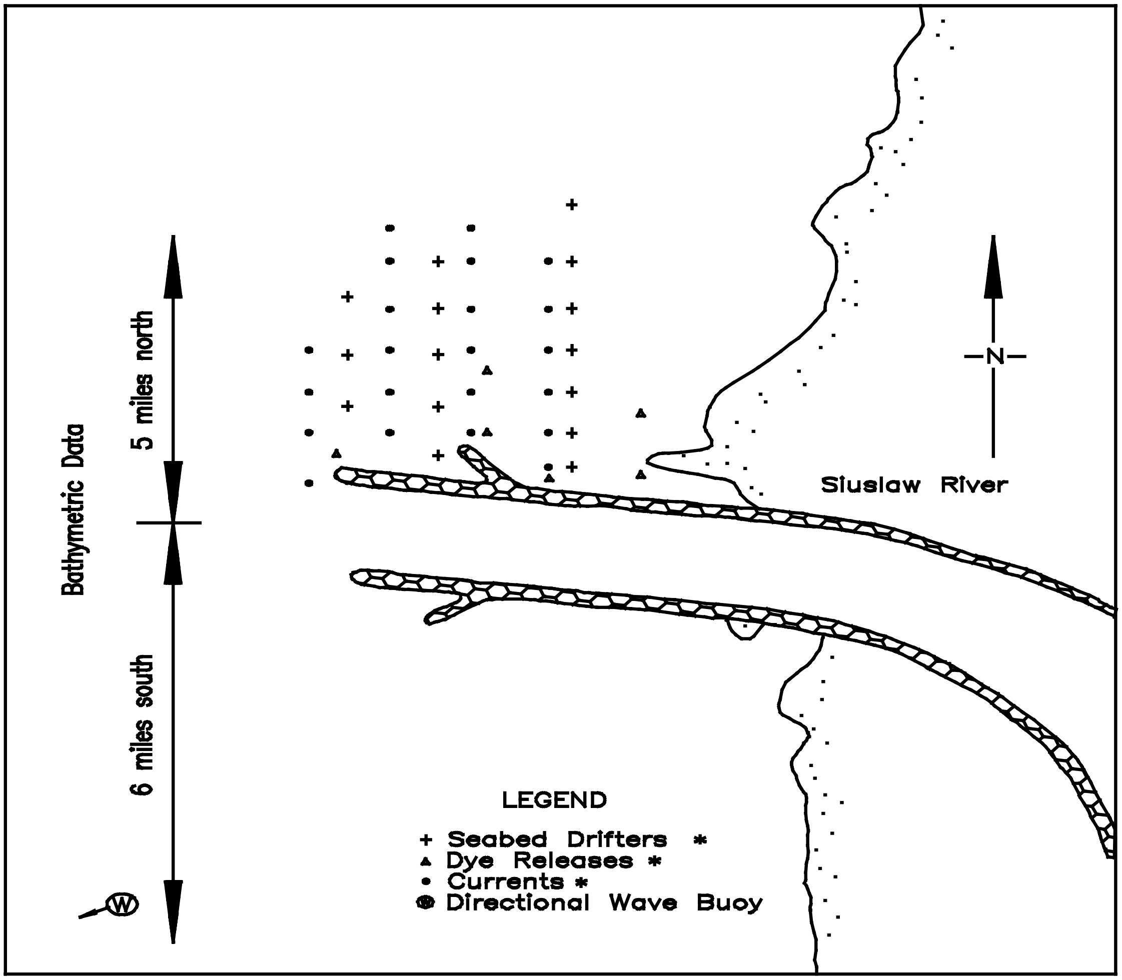

Figure 8-3. Data collected at Siuslaw, Oregon, detailed field study (*note that seabed drifter, dye, and current data were also measured south of the project)

permanent directional gauge located at Coquille, Oregon, approximately 97 km (60 miles) south. Once a correlation between the two gauges is known, data from the Coquille gauge can be adjusted for use at Siuslaw.

(6) Pre- and post-construction dredging data are being compiled and correlated with bathymetric changes, current speeds and directions, and wave information to determine impacts of the spur jetties on coastal processes.

8-6. Summary

a. Tidal inlets are dynamic coastal features that are fascinating to observe because of the rapid changes that can occur, driven by waves, tides, winds, sediment supply, structure design, and channel cross section. For engineering works to be successful, they must be in harmony with the physical processes and geographical constraints that exist at the inlet. Data necessary for a proper engineering design come from a monitoring project that has been designed to answer the critical questions.

b. It must be emphasized that data analyses should be performed during or immediately after the field work at each phase of a monitoring program. If critical measurements have been lost, there still may be time to deploy another instrument and try again. Since many new instruments perform data conversion and analysis internally or in the field by means of portable computers, quality control has improved. It has become easier to decide onsite if the instruments are performing properly, or whether a modification of the experiment is in order. In addition, field notes are available and memories of the participants are fresh during or immediately following the data collection effort.

c. Three phases to a field study have been described: reconnaissance, preliminary measurements, and detailed field study. Some level of reconnaissance is necessary for every monitoring project, although one or both of the latter phases may be omitted, depending on the purpose of the monitoring program. However, the critical process of any monitoring program, at every level, is proper planning.